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THE PRESENT STATUS OF OUR KNOWLEDGE OF X-RAYS

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BY

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Great was the excitement and curiosity aroused in 1895, when it was announced that a new kind of radiant energy had been discovered, by means of which it was possible to photograph the unseen. The reports at that time stated that while Prof. W. Röntgen of Würzburg was experimenting with a cathode tube, a near-by photographic plate although covered, had been so acted upon by some emanation from the tube that a sort of photograph was taken of the objects above the plate. Since X is the symbol most often used in algebraic expressions to represent the unknown quantity, this radiation was called "X-Rays", by their discoverer, because of their unknown origin. At the present time, these rays are as often and more appropriately called "Röntgen Rays". The term "ray" was applied because of the fact that they behave like light in producing shadows.

The reports stated that the discovery was made by chance. But was it so? Although an accident may have hastened the time, not through pure chance or accident was the discovery made. Ever since the manufacture of Geissler tubes, the character of the discharge of electricity in gases had been carefully studied. Each improvement in making these tubes was followed by a greater knowledge of the discharge. Crooke's tube aided the work along this

line very materially. For many years previous to 1895, physicists had felt that the subject of cathode rays was the most important in electricity and many experimenters devoted their entire attention to the study of these rays.

Among others interested in this work was Lenard at Bonn who showed that it is possible to make the cathode rays emerge from the vacuum tube by placing an aluminum window opposite the cathode. This stream could be deflected by a magnet and had the power to effect a photographic plate very slightly.

Röntgen performed the experiments of Lenard independently and discovered further that there was also a new kind of radiation generated in the tube. This new radiation proceeded from the place where the cathode rays struck either the glass or some other obstacle and it was to this radiation that he gave the name "X-Rays". These rays pass through glass and many other substances opaque to light, and cause certain crystalline solutions to become highly fluorescent. If a portion of the human body be placed between an X-ray tube and a screen covered with such a solution, a very marked shadow picture of the skeleton is seen; the bones appear very dark against a much lighter background.

Possibly Lenard had studied these same rays at a short distance from the tube, but it remained for Röntgen to realize that they constitute a new kind of radiation and to

make the fact known to the public.

During the first year after the announcement of the discovery, so great was the interest taken in this subject that thousands of articles were written upon it both in popular and scientific form. However, most of the experiments carried on were simply repetitions of those described by Röntgen. In fact, Röntgen had so far investigated the phenomena that but little was contributed to the results he had given. That these rays differ from cathode rays in not being deflected by a magnet, that they can not be refracted, and do not exhibit diffraction or interference was known to Röntgen.

Since the X-rays are closely associated with cathode rays, the nature of the latter must first be understood. Two different theories are proposed. One is that the cathode rays are a something- just what is not clear- going on in the ether. The other theory is that the cathode stream consists of a great number of exceedingly small charged particles or electrons moving with enormous velocities. This latter theory is now the one generally accepted.

Just as formerly the cathode rays occupied the attention, now the Röntgen rays came into prominence. In 1905, Erich Marx conducted a series of clever and ingenious experiments pertaining to the measurement of the velocity of these rays. The principles upon which this measurement was based were a comparison of their velocity with that of

light, and the effects which these rays produce, namely: their ability to cause the emission of cathode rays and to ionize a gas.

Two Röntgen tubes were arranged one above the other as shown in plate I; the lower tube B, was incased in a lead box to prevent any influence from outside sources. The upper tube A, was excited with short Hertz oscillations and the rays were permitted, after passing through a known distance, to fall upon an electrode P, of tube B. This electrode was connected with the tube through a small condenser over a movable bridge D. Through this inductive coupling, the electrode oscillated with the Röntgen tube, but with a phase difference which could be controlled by varying the length of the wire. Opposite the electrode P, in the lower tube was a Faraday cylinder C, connected with an electrometer, by means of which the phase met on the electrode was made known.

If the tube distance between A and B is constant, then the phase met on the electrode can be varied by the position of the movable bridge D. The bridge shifting can be compensated for by shifting the position of the tube A. When this compensation is effected, then the known time which the electric waves need to pass over double the distance through which the bridge is shifted will be equal to the unknown time which the Röntgen rays need to pass over the displacement space of the tube. The proportionality

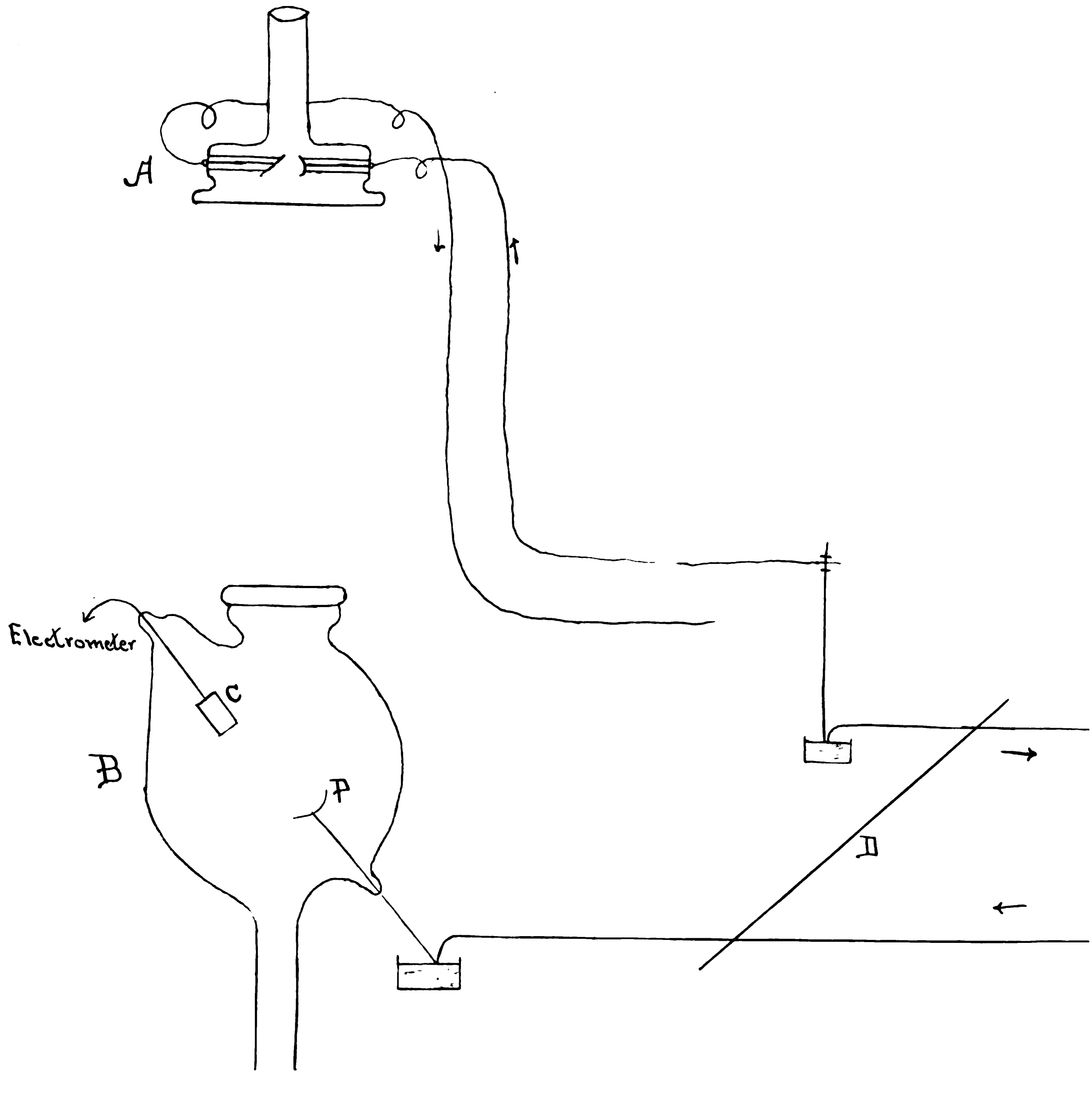

Plate I.

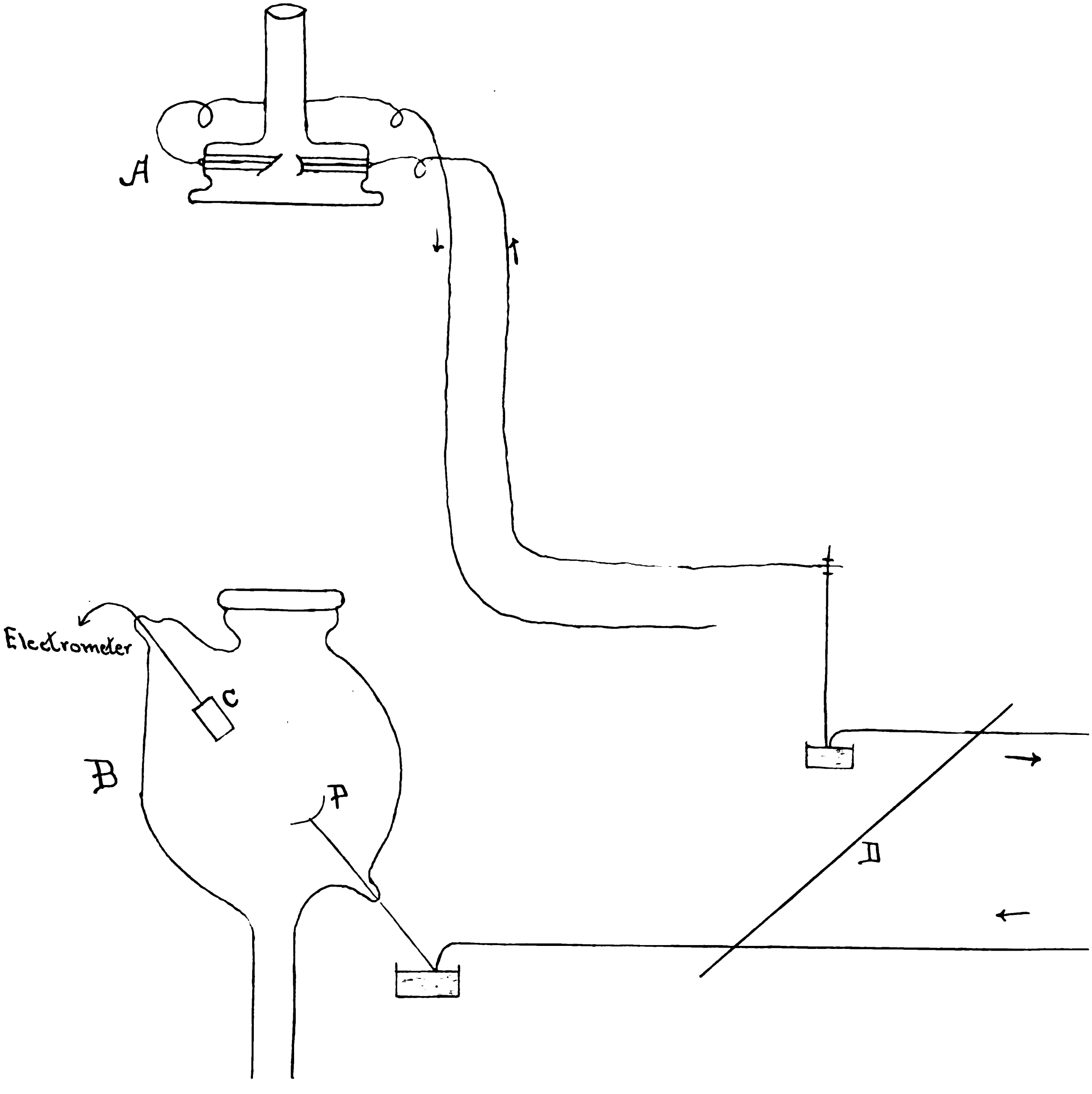

Plate I.

of bridge shifting to Röntgen tube displacement gives the proportionality of light velocity to Röntgen ray velocity.

As a result of his investigations, Marx obtained data for Röntgen ray velocity differing from light velocity by about ½%. This striking similarity led him to infer that the velocity of Röntgen rays is equal to the velocity of light. Although opinion is somewhat divided as to the validity of the conclusion drawn from these experiments, the inference drawn by Marx is generally accepted.

Much difference of opinion exists as to the nature of Rontgen rays. Röntgen himself in his early communications seemed to hold the view that these rays were possibly longitudinal vibrations in the ether; but because he made no mention of it in his later publications, it is assumed that he gave up the idea. The theories are based upon results obtained from experiments on secondary radiation produced by X-rays, ionization of gases by these rays and absorbability.

Whenever a primary X-ray strikes a substance, cathode rays, β-rays, and secondary X-rays start off from the place of impact. According to Barkla and Sadler, the character of the secondary radiation is independent of the intensity of the primary radiation which produced it. Scattered X-rays form the bulk of the secondary radiation obtained from probably all elements when subjected to a primary beam of low or moderate penetrating power. Besides

the scattered radiation, there is emitted also a homogeneous radiation characteristic of the substance which is produced by the motion of the electrons uncontrolled by the electric force in the primary beam. The intensity of this radiation does not depend on the plane of polarization of the beam producing it and the intensity in a direction opposite to that of propagation of the primary beam is equal to that in a direction at right angles. The conclusion is, that the secondary radiation is of the nature of Röntgen rays, and that it is caused by the disturbance of electrons, produced either directly or indirectly by the passage of electromagnetic pulses. The fact of the equality of intensities in directions opposite and at right angles to that of the primary, and the independence of the penetrating power of the secondary beam upon that of the primary, led to the idea that the motion of the electrons was not controlled by electric forces in the primary. The forces which produce the acceleration resulting in radiation must be forces called into play within the atom.

Suppose an electromagnetic pulse passes over an electron. The electron receives an impulse if its free period of vibration is greater than double the time taken for the pulse to pass over it, and the electron is left with kinetis energy after the pulse has passed. It is then acted upon by forces within the atom itself, which produce a

motion characteristic of the atom of which the electron is a part. This results in radiation. But if the primary pulse is thicker, approaching in magnitude the half wave length of the free vibration of the electron in the atom, then energy will be absorbed and subsequent radiation diminished. According to this theory, energy is taken from the primary beam and part of it appears as secondary homogeneous radiation. Röntgen rays are then supposed to consist of electro-magnetic pulses in the ether caused either by impact of electrons with or their escape from matter.

Laue, Friederich, and Knipping, by using the regular arrangement of molecules in a crystalline substance as a diffraction grating, obtained sharp photographic patterns which resemble closely the diffraction patterns in light. They believe this to be evidence that at least some types of X-rays possess a periodic character, and suggest that perhaps X-rays are white light of very short wave length.

Directly opposed to the pulse theory is one which assumes that X-rays possess mass as well as energy. This is the supposition of Bragg and Madsen who base their theory upon the lack of symmetry between the radiation on the two sides of a substance when exposed to X-rays. This radiation was measured by means of its ionization effects. Cooksey's experiments consisted in passing X-rays normally through a metal plate into ionization chambers, to which were connected electrometers. The effect produced by the

incident rays was from 50 to 90% of the effect produced by the emergent rays. There are but three possible sources from which the energy and the material of this secondary radiation may be obtained; the energy and the material might be furnished by the atom alone; the energy might come from the X-ray and the material from the atom; or both the energy and the material might come from the X-ray.

If the energy and the material for the secondary radiation come from the atom alone, then the X-ray would be a pulse which widens out and as it widens, here and there it meets an atom which it discharges and from which it sends out an electron. This theory fails to explain the results of experiments.

Suppose the energy of the secondary radiation comes from the X-ray and the material from the atom. Then the X-ray would be a bundle of energy having mass, which when it strikes an atom, drives the electron out before it. This is the view held by J. J. Thomson who looks on the X-ray as a kink in the tube of force by which he represents all the properties of the electron.

Because a characteristic ether pulse spreads out from the origin, its energy spreads over larger and larger surfaces and consequently becomes weaker. But since the energy of the secondary pulse is much greater than could be given to it by this weakening pulse, Thomson modified the pulse theory. Briefly, he assumes that when a number of

cathode particles strike the anti-cathode, they are not brought to rest by the first collision, but rebound from molecule to molecule. The tube of force attached to the corpuscle is jerked about by the collisions and a series of small disturbances travel out along the tubes. The energy resides in the kink in this tube of force, caused by the stopping of the cathode particle. The energy is supposed to be concentrated along radial lines with their center at the place where the primary cathode ray was either stopped or accelerated. The wave front of the pulse consists of "bundles of energy" occupying but small portions of the front, the rest being blank. If the energy of the bundle is derived from the cathode particle which was stopped then the energy of the bundle must be less than that of the cathode particle. But the energy of the electron of the secondary radiation is nearly as great as that of the primary cathode corpuscle. The conclusion is that the whole of the energy of the cathode particle in the X-ray tube is converted into one energy bundle. This flies away from the anti-cathode and some times causes an electron to be ejected from the atom through which it passes and to this electron it gives over the whole of its energy. While this offers an explanation for the well known fact that X-rays pass over all but an exceedingly small fraction of the atoms in space without influencing them in any way, it also complicates very greatly the idea of the ether structure

and does not offer an explanation of all phenomena.

If both the energy and the material come from the X-ray then the X-ray can not be a pulse. To solve the difficulty, Bragg offered his "neutral pair" hypothesis; that is, of "doublets" or "neutral pairs", positive and negative. When passing through an atom, the bond between the positive and negative is dissolved. The negative flies on with its velocity nearly as great as the original cathode ray. The positive becomes ineffective. All the energy of the cathode particle is converted into one energy bundle which darts away from the anti-cathode. When this energy passes through an atom, it causes an electron to be ejected, to which it hands over its own store of energy.

The "neutral pair" hypothesis demands the existence of a positive counterpart to this negative electron. What this positive counterpart is, is of no consequence. It may be an α-particle or it may be a positive electron. The only thing necessary is that it shall exist, and that it can be torn from its attachment to a negative, and after awhile can be left behind.

Experiments show that cathode radiation from a given layer of matter through which X-rays are passing, possesses momentum in the original direction of the rays. This could be explained on the theory that the X-rays are material. Lack of symmetry on both sides of a plate can also be explained on this hypothesis. Bragg says there are a few

phenomena of X-rays, such as the measurement of the velocity by Marx and diffraction experiments by Laue, Haga, and others which do not fit in with this theory. This would seem to prove the existence and activity of ether pulses.

Barkla found that the primary beam coming from an X-ray tube in a direction perpendicular to that of the propagation of the cathode stream was partially polarized and the secondary rays proceeding in a direction perpendicular to that of propagation of the primary was almost completely plane polarized. Bragg considers that this might be explained as a consequence of the rotatory motion of the neutral pair. A pair might be more likely to become entangled with and deflected by an atom revolving in the same plane as itself. Later he asserts there should be ether pulses in the X-ray stream and it may be these which show these polarization effects. Barkla feels that these polarization effects are easily explained on the ether pulse theory. The fact that the results of experiments on scattered radiation were predicted long before the experiments were carried out and that the predicted values were within 5% of the observed values strengthens his belief in the ether pulse theory.

The ultimate nature of X-rays is still a question open for discussion. The lack of symmetry between the radiation issuing from the sides of a plate through which X-rays are passing, easily explainable if these rays are

material, led Bragg to formulate his neutral pair hypothesis. However, all the principal experimental results: the ionization of a gas through which X-rays are passing, diffraction effects, polarization of the primary beam from an X-ray tube, and scattering of X-rays, are favorable to the pulse theory, supported by Barkla, Ayres, Sadler, Rutherford and J. J. Thomson. Would it not be more reasonable to look to this for an explanation of the rays, remembering that lack of symmetry is a difficulty yet to be explained?

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